6. SUMMARY AND CONCLUSIONS

This paper discusses an impulse response measurement experiment consisting of measurements taken in the 1850-1990 MHz band within three different cell environments in the Denver, Colorado, area. These environments included a flat rural cell, a hilly rural cell, and an urban high-rise cell. The measurements within each cell were made using a fixed-location receiver placed at the center of the cell and a mobile transmitter installed in a measurement van. A single binary phase-shift keyed (BPSK) PN code sequence was transmitted and a dual-channel receiver employing spatial diversity was used to receive the transmitted signal. The separation of the receive antennas was set for 15 wavelengths at the center of the 1850-1990 MHz band. In the rural cells, the receiver was located in a large measurement van and kept at a fixed location. The receive antennas were mounted on a telescoping mast 8.7 m aboveground. In the urban high-rise cell, the receive antennas were located on the rooftop of a building 103 m aboveground in the center of the high-rise district in downtown Denver. The building height was typical for the buildings in this area. All of the measurements were made within a 5-km radius of the center of each cell. The measurements were taken using omnidirectional, vertically polarized transmit and receive antennas in all of the cells. Impulse response data were collected as the transmitter van travelled along predetermined routes within each cell. A rapid succession of 10 impulse responses was taken at intervals of approximately 0.7 s while the transmitter van was moving. Within this succession of 10 impulse responses, a time interval of 255.5 µs (5 times the PN code word duration) was used between the beginning of one impulse and the beginning of the next. This allowed for averaging of 10 impulses to reduce the noise floor. The data were analyzed to provide delay statistics; spatial diversity statistics; multipath power statistics; number of paths, path arrival time, and path power statistics; and correlation bandwidth statistics.

Three types of delay statistics were presented: maximum delay, average delay, and RMS delay spread. From these statistics, several conclusions were suggested. Slightly more multipath was seen in the hilly rural cell than in the flat rural cell. Very long delays (greater than 10 µs), while not seen often, were seen more frequently in the rural cells than in the urban high-rise cell. Although very long delays were seen more often in the rural cells, there were many more delayed signals (out to 5 or 6 µs) with higher power in the urban high-rise cell than in the rural cells. More signals with long delays (greater than 6 µs) were seen in the hilly rural cell than in the other cells.

The effects of spatial diversity were analyzed by comparing the cumulative distribution of RMS delay spread between Channel 1, Channel 2, and the diversity combination of both channels. The results of this analysis showed some, although not a large, decrease in RMS delay spread values using diversity combination. These results suggest that the wideband signals seen on each channel were indeed uncorrelated to some degree.

The multipath power statistics provided statistical information about the signal amplitude variation for every delay time for all of the APDPs in a given cell. These statistics included, as a function of delay time: average multipath power, standard deviation of multipath power, peak multipath power, and probability of multipath power exceeding a threshold. The results of these analyses agreed very well with those from the delay statistics. The urban high-rise cell had many more multipath components above threshold than the rural cells, out to 4 or 5 μs in delay. The peak (normalized) multipath power was also seen to be the highest for delays greater than 15 μs in the hilly rural cell and the lowest in the urban high-rise cell.

The goal of the presentation of the number of paths, path arrival time, and path power statistics was to provide information to assist in the development of impulse response models (primarily tapped delay models) of the radio propagation channel. The results provide an idea of the number of required taps that may be needed to model the impulse response of the radio channel (within a 100-ns resolution) in several different environments in the 1850-1990 MHz band. The results clearly showed that the urban high-rise cell would require a far greater number of taps than the rural cells for the -20 and -10 dB thresholds. It should be noted that these results, and the rest of the results of the data analyses presented in this paper, are quite dependent on the threshold level used in processing. As expected, processing with lower threshold levels (i.e., those set further below the peak in the APDP) showed more paths. Mean and standard deviation of the arrival time and path power of each individual path were presented for APDPs having a total of up to 10 paths. For a threshold of -20 dB, it was found that 10 paths can adequately represent most (89% or more) of the APDPs in each of the rural cells. In the urban high-rise cell, for a -20 dB threshold, 10 paths are not adequate to represent most of the APDPs. For a threshold of -10 dB, most (79% or more) of the APDPs in each of the cells can be adequately represented with 10 paths.

The results of the correlation bandwidth statistics show only small differences in the cumulative distributions of correlation bandwidth between the rural cells. The urban high-rise cell shows much smaller correlation bandwidth values than in the rural cells. This indicates that significantly more multipath was seen in the urban high-rise cell than in the other cells; consistent with the findings in the other forms of data analyses presented here.

Finally, it should be noted that these impulse response measurements were made with a system having a 20 MHz bandwidth. The results are expected to be different for measurements taken with systems having different bandwidths.